Equiaxed Dendritic Solidification Experiment (EDSE)

Professor C. Beckermann Department of Mechanical Engineering University of Iowa Iowa City, IA 52242-1527

Co-Investigators: I. Steinbach, ACCESS e.V.

A. Karma, Northeastern University

H.C. deGroh III, NASA Lewis Research Center

Objectives

The objective of the research is to quantitatively determine and understand the fundamental mechanisms that control the microstructural evolution during solidification of an assemblage of equiaxed dendritic crystals. A microgravity experiment will be conducted to obtain benchmark data on the transient growth and interaction of up to four equiaxed crystals of a pure and transparent metal analog (succinonitrile, SCN) under strictly diffusional heat flow conditions.

Of interest in the experiment are the transient evolution of the primary and secondary dendrite tip speeds, the dendrite morphology (i.e., tip radii, branch spacings, etc.) and solid fraction, the tip selection criterion, and the temperature field in the melt for a range of initial supercoolings and, thus, interaction "strengths" between the crystals. The experiment thus extends the microgravity measurements of Dr. Glicksman and co-workers for steady growth of a single dendrite [Isothermal Dendritic Growth Experiment (IDGE), first flown on USMP-2] to a case where growth transients are introduced due to thermal interactions between neighboring dendrites – a situation more close to actual casting conditions. Corresponding earth-based experiments will be conducted to ascertain the influence of melt convection. The experiments are supported by a variety of analytical models and numerical simulations. The data will primarily be used to develop and test theories of transient dendritic growth and the solidification of multiple interacting equiaxed crystals in a supercooled melt.

Need for Microgravity

Experimental validation of present equiaxed dendritic solidification models is very limited, with only a few bulk solidification experiments conducted (on earth) using metal alloys. There are basically four issues that have hampered the testing of such models: (i) the inability to control and quantify nucleation; (ii) the presence of uncontrolled, gravity-driven melt convection and crystal movement; (iii) the difficulty to observe growth in metallic systems; and, (iv) the complications associated with coupled thermal and solutal undercoolings when using alloys. The Equiaxed Dendritic Solidification Experiment (EDSE) is designed to be simple, yet overcomes all of these limitations. In particular, even with an initially isothermal sample, gravity-driven convection caused by latent heat release can only be minimized in a microgravity environment. Due to our inability to analyze solidification microstructure evolution in the presence of this convection, it is important to first generate benchmark data for the diffusion limit.

Results

The research to date has concentrated on:

(i) development of the science requirements for the proposed microgravity experiment;

- (ii) design, construction, and testing of a ground-based version of the experiment; and,
- (iii) modeling of the growth of an assemblage of equiaxed dendritic crystals.

These efforts have culminated in the passing of the Science Concept Review (SCR) held at NASA Lewis Research Center in February 1998. The research team is now preparing for the Requirements Definition Review (RDR). Some of the experimental and theoretical research is described in greater detail below.

Ground-Based Experiments

We have conducted preliminary experiments involving an assemblage of equiaxed crystals using a setup that is functionally similar to the planned EDSE. A glass growth chamber is contained within a temperature regulated bath. Four Charge-Coupled Device (CCD) cameras, with light sources, provide orthogonal images from four sides. The growth chamber contains pure SCN, several thermistors, and four stingers on which the dendrite growth is initiated. The tips of the stinger tubes are located at the corners of a tetrahedron with edge lengths, and hence spacing between the tips, of 10 mm. Thermoelectric coolers are mounted on the stinger ends opposite to the tips. An experiment starts by melting the SCN and establishing the desired supercooling level in the growth chamber. Then, the thermoelectric coolers are initiated and, after some time, dendrites start to emerge at the stinger tips. Although the present setup does not yet allow for a quantitative evaluation of the growth phenomena, we have performed image analysis in order to demonstrate some of the measurement techniques. We have also used this setup to examine numerous issues regarding the design of the planned microgravity experiment, including dendrite initiation, imaging requirements, stinger design, and others. We have clearly established the feasibility of the proposed experiment and measurement techniques.

Modeling

The proposed microgravity experiment is supported by several modeling efforts, that are not only intended to provide the theories that will be tested using the microgravity data, but will also be used to simulate the experiment. Work has concentrated on the development of four models:

- (i) a modified Ivantsov theory for multiple dendrites;
- (ii) a unit-cell model for equiaxed solidification;
- (iii) a mesoscopic simulation model for simulating the experiment; and,
- (iv) a phase-field model for direct microstructure simulation.